



# General Aviation Light Aircraft Propulsion: From the 1940's to the Next Century

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## GENERAL AVIATION LIGHT AIRCRAFT PROPULSION: FROM THE 1940'S TO THE NEXT CENTURY

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### Summary

Current general aviation light aircraft are powered by engines that were originally designed in the 1940's. This paper gives a brief history of light aircraft engine development, explaining why the air-cooled, horizontally opposed piston engine became the dominant engine for this class of aircraft. Current engines are fairly efficient, and their designs have been updated through the years, but their basic design and operational characteristics are archaic in comparison to modern engine designs, such as those used in the automotive industry. There have been some innovative engine developments, but in general they have not been commercially successful. This paper gives some insight into the reasons for this lack of success. There is now renewed interest in developing modern propulsion systems for light aircraft, in the forefront of which is NASA's General Aviation Propulsion (GAP) program. This paper gives an overview of the engines being developed in the GAP program, what they will mean to the general aviation community, and why NASA and its industry partners believe that these new engine developments will bring about a new era in general aviation light aircraft.

### Introduction

Light aircraft engines have had a long history of development. The first successful aircraft engine was the Wright brothers' engine, which powered their Wright Flyer in its first flight in 1903. Since that time, practically every piston engine configuration imaginable has been tried. Mechanical layouts from inline to radial and beyond were proposed and built. Two- and four-stroke engine designs were used with spark and compression ignition. Air cooling and liquid cooling were tried. Engines using every combination of these mechanical layouts, cycle types, and cooling types have been successfully flown. Yet today, the air-cooled, horizontally opposed, four-stroke, spark-ignited engine is the only configuration to survive as a mass-produced, certified light aircraft piston engine. The reasons for this and why the turbine engine has not been able to penetrate the light aircraft market to any significant extent are explored in this paper.

It appears that we are now at a turning point in the history of light aircraft engines, with new technologies and manufacturing techniques within reach that will have a major impact on the light aircraft engines of the future. NASA's General Aviation Propulsion (GAP) program is developing two new light aircraft demonstration engines, in cooperation with industry, which will provide a revolutionary quantum leap over current engines in affordability, ease of use, and comfort. This paper describes the program, the engines being developed, and their impact on the industry.

### Evolution of the Light Aircraft Engine

The internal combustion piston engine was the first manufacturable engine that had a high enough power-to-weight ratio to meet the requirements of powered, heavier-than-air flight. Figure 1 shows the Wright brothers' engine, which powered the first successful heavier-than-air aircraft flight in 1903. This was a liquid-cooled, four-stroke, spark-ignited, internal combustion piston engine—just one of many possible configurations of the internal combustion piston engine. Over the years, most of the possible configurations have been tried with more or less success. This paper covers only the "standard piston" engine, that is, an engine with a piston that reciprocates within a cylinder connected to a crank shaft via a connecting rod (fig. 2). This is by far the most successful type of internal combustion engine. Other types, including cam engines and vane engines, have been proposed and tried, but in general have not been successful because of mechanical design difficulties and/or lack of adequate materials.

Over the years, the cooling method has probably been one of the most controversial configuration issues with respect to aircraft engines. Both liquid and air cooling have advantages and disadvantages, and there is no clear answer to which is better. The type of cooling selected depends in large part on the preferences of the designer and end user. In the early years, most medium to high power output engines were water cooled, with the exception of the infamous rotary engines, because air-cooling techniques were not developed sufficiently to handle the high heat loads of these more powerful engines. Air-cooling techniques improved considerably over the years, as evidenced by the increase in cooling area per horsepower. In the mid-1920's typical cooling

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areas were on the order of 25 in.<sup>2</sup>/hp, and by the mid-1940's they were on the order of 35 in.<sup>2</sup>/hp. With these improvements in air-cooling techniques, air cooling was also successfully used on high power output engines. Air-cooled engines tend to be lighter and simpler. When running at high power outputs, though, they usually require rich fuel mixtures, with the heat of vaporization of the extra unburned fuel being used to help cool the engine. This results in poor fuel economy and high emissions at high power. Air-cooled engines can also be sensitive to what is called thermal shock; that is, overcooling during sudden reductions in power, which may result in engine damage.

Liquid cooling allows better control of the engine heat loads, which enables more efficient fuel usage, results in less cylinder distortion, and permits tighter design tolerances. The radiator can be placed in its most efficient location in the airframe for drag reduction and structural efficiency. However, liquid cooling has the disadvantage of introducing another subsystem to the engine, which adds weight, cost, and additional mechanical failure modes.

Historically, most light aircraft engines have been air-cooled because of the importance of simplicity and lower cost in this class of aircraft. This has continued to be the trend to the present day with essentially all of today's commercial light aircraft engines being air-cooled.

The preferred cycle type was settled by the 1920's. Two- or four-stroke cycles can be used with either spark or compression ignition (fig. 3). (Compression-ignition engines are more commonly referred to as diesel engines.) Compression-ignition engines require high compression ratios (greater than 14:1) because gas temperatures above the fuel auto-ignition point must be developed during the compression process for the fuel to ignite. The high compression ratio requires a heavy structure to withstand the stresses developed. Therefore, although compression-ignition engines tend to be more fuel efficient because of the high compression ratio, they are also much heavier than spark-ignition engines of equivalent power. Because aircraft greatly benefit from lightweight components, compression-ignition engines never were major players as aircraft powerplants.

In the early years, two-stroke engines were given much consideration for aircraft because of their greater reliability and power-to-weight ratio in comparison to four-stroke engines. Two-stroke engines tend to have fewer moving parts because the piston is used to open and close the intake and exhaust ports; a separate mechanical valve system is needed for four-stroke designs. Also, fuel and oil are mixed and used for lubrication in most two-stroke designs—so as long as the engine is getting fuel, it is being lubricated. These two design features made early two-stroke engines much more reliable than the four-stroke engines of that time.

Two-stroke engines can attain higher power-to-weight ratios because a two-stroke engine has one power impulse with every stroke of the piston, whereas a four-stroke engine requires two piston strokes for every power impulse. Therefore, if everything were equal, a two-stroke engine would develop twice the power of a four-stroke engine running at the same speed. In reality, that does not quite hold true because of the less efficient breathing associated with the two-stroke process.

The major drawback of the two-stroke configuration is its lower fuel efficiency when it is applied to spark-ignition engines, as much as 60-percent greater fuel consumption. Until recently, in virtually all spark-ignition engines, the fuel and air were premixed before they were taken into the cylinder to ensure a homogeneous air-fuel mixture for proper ignition and burning when the spark was produced. Also, premixing the fuel through carburetion or manifold injection is mechanically much simpler and less expensive than direct in-cylinder fuel injection. Because intake and exhaust must occur simultaneously in a two-stroke engine, it is inevitable that some of the fresh fuel-air mixture will be lost through the exhaust port, wasting fuel. As the art of piston engine design progressed, reliability increased. By the mid-1910's, the two-stroke engine's lack of fuel efficiency resulted in its no longer being a major player except for very small engines.

The final major engine configuration issue was the mechanical layout of the engine: that is, its shape and the alignment of its cylinders. The four basic types were the inline engine, the V-engine, the horizontally opposed engine, and the radial engine (fig. 4). Progressing from the inline to the radial configuration, for a given power output the engine usually becomes lighter. However, it grows in frontal area, which tends to increase drag. Mechanical layout also affects the difficulty of cooling an air-cooled engine. Much more attention to the air ducting system is needed to ensure good cooling of cylinders that fall directly behind other cylinders, as occurs in all configurations other than the radial configuration, with the inline configuration being the worst case of this. The inline engine tends to be heavier than the radial because of the long, multiple-throw crankshaft, which is more massive than the short, single-throw crankshaft of the radial. Additional mass is required for stiffness in long inline configurations, and additional counter weighting is required to overcome the rocking moments, which do not exist in a radial configuration.

A special, interesting case of the radial engine was the rotary engine. In this engine, the crankshaft was fixed to the airframe and the engine case rotated with the propeller. This type of engine was very popular in World War I because it was light, smooth running, and had very good cooling characteristics. Its smoothness was due, in part, to the fact that the pistons did not reciprocate with respect to the aircraft but merely

orbited in a circle. Also, the spinning case acted as a flywheel, which smoothed out the torque pulses. However, this also had the detrimental effect of causing large gyroscopic forces during maneuvering, which the pilot had to compensate for. The main drawbacks of the rotary engine that made it unsuitable for general aviation were its extreme unreliability and the difficulty of putting an exhaust manifold and carbureted fuel-air delivery system on a rotating engine. The unreliability of these engines was due in part to extreme efforts to reduce weight for military purposes; however, even with that consideration, they tended to be less reliable than their contemporary water-cooled inline counterparts. The lack of an exhaust manifold made them very unpleasant to fly behind, and the primitive fuel supply system resulted in poor fuel efficiency and lack of throttleability.

From the mid-1920's to the mid-1930's, the air-cooled inline engine was considered to be the best light aircraft engine. It was lighter and simpler than the liquid-cooled inline engine and produced less drag than the radial engine. The high drag of radial engines was overcome with the invention of the NACA cowl in the early 1930's, making radial engines competitive for higher speed aircraft by the mid-1930's.

For single-engine aircraft, figure 5 shows a major disadvantage that all other configurations have in comparison to the horizontally opposed configuration. The Cessna 182, which has a horizontally opposed engine, has much better over-the-nose visibility than the Cessna 190, which has a radial engine. The horizontal configuration allows a higher thrust line with better forward visibility than do any of the other configurations.

An inverted inline or V-configuration would give a high thrust line also, but it is not as easy to accommodate retractable front landing gear. A particular consideration with inverted engines is the problem of hydraulic lock. Oil can drain down past the piston into the combustion chamber. If the engine sits unused for awhile, a volume of oil larger than the combustion chamber volume at the piston's top-dead-center can drain into the combustion chamber. If it is not drained before someone tries to start the engine, the piston will push up against the oil when the engine is cranked, and since oil is incompressible, it will not be able to extend to full top-dead-center and the engine will be damaged.

The horizontally opposed piston engine integrates well with modern single-engine aircraft. There is little to no additional drag penalty because the engine fits within the width of the side-by-side seating arrangement of virtually all post-World War II light aircraft designs. It allows a high thrust line with good over-the-nose visibility. Compared with a radial engine with the same number of cylinders, an opposed engine would be heavier; however, because of balance considerations, for the same smoothness of operation, a radial engine requires more smaller cylinders than an opposed engine does. Therefore, in practice, opposed engines in this

size class are short and compact with little to no weight penalty in comparison to radial engines. Finally, since a small number of cylinders are lined up on each side of the engine, air cooling is not a major problem. For these reasons, the air-cooled, horizontally opposed engine has virtually displaced all other piston engine configurations in the light aircraft arena.

The granddaddy of all horizontally opposed engines is the Continental A-40 (fig. 6). This engine was 115 in.<sup>3</sup> in displacement, produced 37 hp at 2500 rpm, and weighed 144 lb. Introduced in 1931, the A-40 was the first popular horizontally opposed engine with more than two cylinders. It had many of the desirable qualities still looked for in general aviation light aircraft engines today. It was smooth, reliable, easy to start, and inexpensive.

By the late 1930's, there were three major manufacturers of horizontally opposed engines for light aircraft: Continental, Franklin, and Lycoming. In 1938, Continental introduced the A-50, which a year later was upgraded to the A-65 shown in figure 7. The A-65 produced 65 hp at 2300 rpm.

Compare this engine with the currently produced Continental IO-240-B (fig. 8), and the design heritage of today's Continental engines is immediately apparent. Virtually all engines currently produced by Continental and Lycoming were originally designed in the 1940's or 1950's. These were excellent engines when they were introduced, and they are still good engines today. Furthermore, the designs have been improved over the years, with upgrades such as the replacement of carburetion with modern electronic fuel injection. Most of these improvements have dealt with engine performance, whereas the manufacturing method and the human factor aspects of the propulsion system have essentially been unaddressed. These two categories include aspects such as noise, vibration, ease of use, and engine cost; and these are the areas where today's piston aircraft engines pale in comparison to modern automotive engines.

There were some attempts at new designs in the 1970's and 1980's. Continental developed and introduced to the market the compact, lightweight, high-revving Tiara and the liquid-cooled Voyager series engines (fig. 9). Lycoming participated early on in the development of the Wankel engine (fig. 10) for aircraft use. Wankel engine development was discontinued, after many years of effort, in the early 1990's. There were still some mechanical reliability problems, and after all was said and done, there did not appear to be that much advantage to the engine over standard engines. Its one major advantage was its stratified-charge combustion system, which enabled it to run on almost any liquid fuel. However, the great promises of low cost and weight were never realized. The stratified-charge combustion system reduced the fuel-to-air ratio the engine could accommodate, and this, coupled with the required gearbox to reduce high crankshaft speeds

to those usable by the propeller, resulted in a power-to-weight ratio not much better than that of other engines. These systems also increased engine cost, so this engine never made it to market. The Continental engines, on the other hand, were not successful in the market.

Why weren't these innovative engines successful? There are many factors, but the basic reason is that they offered nothing except minor benefits in performance over engines already in the marketplace. In a thriving market, such benefits could have been justified; but in a depressed market, the cost of incorporating these engines into aircraft was greater than the profits they would produce.

### Turbine Engines

Turbine engines make very good aircraft engines as is evidenced by their complete takeover of aviation propulsion except for the light aircraft market. Turbine engines, such as the Allison Model 250 (fig. 11), have been introduced into this market. However, they have not made major inroads into the market and mainly find use in niche markets. Although most turbine engines are not quite as fuel efficient as piston engines, they are much lighter, which helps to reduce aircraft weight and partially offsets their higher fuel usage rate. In every other way it can be argued that turbine engines are superior to piston engines for aircraft applications. They have an Achilles heel, however: they are extremely expensive. In the light aircraft marketplace, that is an overwhelming detriment. A turbine engine propulsion system can cost more than the piston-powered aircraft that it might be considered for. Therefore, turbine engines have only been able to penetrate, to a small extent, the top-of-the-line luxury light aircraft market.

### General Aviation Light Aircraft Marketplace

The general aviation light aircraft market once thrived, having a sales trend that generally followed the gross national product. Single-engine aircraft sales peaked at over 14,000 aircraft per year in 1978 (fig. 12). However, just after this peak, sales began to sharply decline. Many factors contributed to this decline, including a reduction in investment incentives, the oil crisis, the loss of postwar government pilot training incentives, and a sharp increase in liability costs spread over a smaller sales volume. The interesting thing to notice is that there was a similar decline in the late 1960's; however, as the economy picked up in the 1970's, so did aircraft sales. This resurgence did not occur in the 1980's.

Figure 12 shows the mean price of single-engine aircraft over the mean average family income for these same years. Aircraft prices began to rise sharply at this downturn, and new aircraft became unaffordable for most individuals, forcing sales down even further and keeping them at a severely depressed level of less than

1000 aircraft per year. In this market, few innovative new products were developed and a pilot could buy good used aircraft with the same performance and comfort characteristics as a new aircraft for less than half the price. The light aircraft market has muddled along in this condition for the last 15 years.

We appear to be at a critical time in the light aircraft market, and there is optimism in the industry that the market is ripe for a turnaround. The average age of the light aircraft fleet is 29 years. Consumer electronics, materials, and engine technologies have progressed to the point where major performance, comfort, and price advances are feasible for light aircraft.

Some of these advances are very prominent in home-built aircraft. Home-built aircraft now outstrip every certified production aircraft in performance and modern avionics. Light aircraft pilots are hungry for these advances and this accounts, in part, for the popularity of home-built aircraft.

The General Aviation Revitalization Act passed by Congress in 1994 relieves some of the burden on manufacturers by limiting their liability to 18 years. In addition, the industry is actively promoting new pilot recruiting and training programs.

Finally, foreign manufacturers are beginning to show interest in this market. For example, Toyota's prototype aircraft engine based on the Lexus V8 automotive engine was type certified recently, meaning that the engine design meets Federal Aviation Administration (FAA) requirements. Before Toyota can produce the engine in quantity, they will also need a production certificate, which certifies that the manufacturing facility produces engines that conform to the type certificate.

### The Challenge

For the light aircraft market to be reinvigorated and the United States to maintain leadership in this market, modern aircraft that meet the needs and desires of the general aviation customer must be developed. Both traditional light aircraft customers and the potential new customer base of those who need affordable, fast, efficient cross-country transportation need to be considered.

An enabling part of this challenge is the development of new light aircraft engines. The NASA Aeronautics Advisory Committee's General Aviation Task Force Report of September, 1993, states that "replacing today's outdated light aircraft propulsion systems is perhaps the most important factor in revitalizing the light aircraft market." There is an old axiom: "New engines beget new aircraft."

In spite of the age of their design, today's engines do perform well. However, as depicted in figure 13, today's engines leave much to be desired. Turbine engines would redress all of these problem areas, but as discussed earlier and depicted in figure 14, their cost

must be drastically reduced before they can become viable engines for this class of aircraft.

To meet the propulsion challenge, NASA has joined with industry and the FAA in the General Aviation Propulsion (GAP) program to develop two new engines that will be the forerunners of the next generation of general aviation light aircraft engines. These engines will change our concept of general aviation propulsion systems. They will bring about a revolution in affordability, ease of use, and performance. With their smooth, quiet operation, they will provide a level of comfort never before enjoyed in general aviation light aircraft. These new engines promise to be the key to creating new demand for aircraft and to revitalizing the U.S. general aviation industry. The potential is especially strong when the benefits of the new propulsion systems are coupled with those of cockpit and airframe technologies being developed by the NASA-FAA-industry Advanced General Aviation Transport Experiments (AGATE) consortium.

NASA's GAP program consists of two elements: the Intermittent Combustion (IC) Engine Element and the Turbine Engine Element. By the year 2000, NASA and its industry partners will develop a revolutionary new piston engine in the IC Engine Element and a revolutionary new turboprop engine in the Turbine Engine Element. That year, both of these engines will be flight demonstrated to the public for the first time at the Experimental Aircraft Association's AirVenture '00. Commercially produced engines based on these engines and manufacturing technologies will soon follow.

#### GAP Program Intermittent Combustion Engine Element

GAP's Intermittent Combustion (IC) Engine Element will demonstrate a new propulsion system for entry-level aircraft. Such aircraft usually have a single engine, no more than four seats, cruise at less than 200 kt, and are easy to handle. The goal of the IC Engine Element is to reduce engine prices by one half while substantially improving reliability, maintainability, ease of use, and passenger comfort.

To achieve this goal, Teledyne Continental Motors and its partners (Aertronics, Cirrus Design, Hartzell Propeller, Lancair International, New Piper Aircraft, and subcontractor Perkins Technology) teamed with NASA to develop a highly advanced piston engine (fig. 15). This engine incorporates many innovations. It is a horizontally opposed, four-cylinder, liquid-cooled, two-stroke, compression-ignition engine. Compression-ignition engines are well known as very reliable but heavy. However, combining the two-stroke operating cycle with innovative lightweight construction will result in an engine that is lighter than today's aircraft engines. The engine will produce 200 hp.

This IC engine will be combined with advanced design, low-speed propellers (from related NASA-industry research) to offer very quiet operation for both

airport neighbors and aircraft passengers. As seen in figure 16, this engine together with the quiet propeller will more than meet expected future noise regulations. Leaded gasoline will be a thing of the past. GAP's IC engine will burn jet fuel at a low fuel consumption rate of 0.36 lb/hp-hr instead of the 0.41 to 0.49 lb/hp-hr for today's engines. Special care is being taken in the design of the engine to ensure smooth, vibration-free operation. There will be no fuel-air mixture or propeller pitch control to contend with. Instead, a single power lever will control the engine and propeller. The engine will provide the same kind of quiet, easy-to-use power that has become the standard in the automotive world. Along with these vast improvements in engine operation and performance, unique design features and the development of low-cost manufacturing methods will have the potential to reduce engine costs to 50-percent of those of current engines.

The GAP compression-ignition engine will be flight demonstrated on a Cirrus SR20, Lancair Columbia, and Piper Seneca IV (fig. 17) in the year 2000.

#### GAP Program Turbine Engine Element

GAP's Turbine Engine Element will demonstrate a new propulsion system concept for higher performance light aircraft. These aircraft usually have four to six seats and cruise at more than 200 kt.

Reducing the price of small turbine engines by an order of magnitude (from hundreds of thousands to tens of thousands of dollars) is the primary goal of the Turbine Engine Element.

Williams International and its partners (Bell Helicopter, California Drop Forge, Cessna Aircraft, Chichester-Miles Consultants, Cirrus Design, Forged Metals, New Piper Aircraft, and VisionAire; subcontractors Producto Machine, Scaled Composites, and Unison; and consultant Raytheon Aircraft) have teamed with NASA to develop a truly revolutionary turbine engine that will set a new standard for general aviation engines. The FJX-2 high bypass ratio turboprop engine (fig. 18) will produce 700 lb of thrust and weigh less than 100 lb. This is a weight advantage of 3 or more over current piston propulsion systems with similar capabilities.

With a bypass ratio of approximately 4:1, the FJX-2 will be fuel efficient and, more importantly, very quiet. It will be 20-dBA quieter than the current Stage 3 regulation for turboprop aircraft, and as shown in figure 19, the FJX-2 will even be very quiet in comparison to today's piston aircraft (which, in general, fall close to the current regulation line).

Emphasis will be placed on simplifying and reducing the number of parts. For example, there will be no mechanical power takeoff and all aircraft power requirements will be supplied electrically. Such low-cost design techniques, combined with the development

of advanced automated manufacturing methods will lead to a turbine engine with the unprecedented potential of being cost competitive with piston engines.

Aircraft powered by commercial derivatives of GAP's turbine engine will have the performance to avoid bad weather and minimize travel time. By taking advantage of the weight and aerodynamic integration benefits of this engine, such aircraft will do this with a takeoff-to-landing fuel burn equivalent to or less than that for today's comparable piston-powered aircraft (fig. 20).

The FJX-2 will be demonstrated in the year 2000 on the V-Jet II (fig. 21). This aircraft was specially built to demonstrate the revolutionary benefits of this engine for future light aircraft designs.

#### Conclusions

New engines enable new aircraft. With the two new engines being developed in the GAP program, general aviation will take an exciting leap forward. The potential for an invigorated general aviation market will be

realized, especially when these engines are combined with advances in airframes and avionics being developed in the AGATE program. Commercial derivatives of these engines will provide a previously unheard of level of comfort and convenience, and there will be a true revolution in the performance-to-price ratio. Flying will not only be fun, it will be comfortable and affordable!

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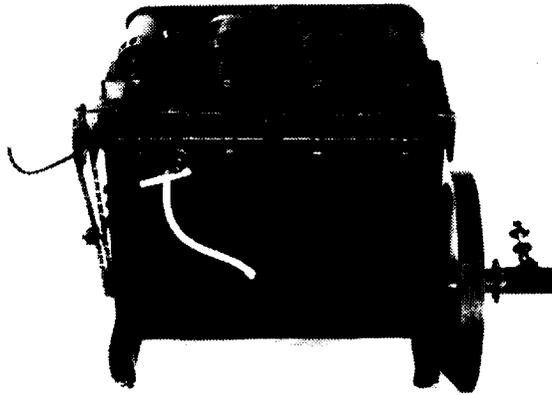


Figure 1.—Wright brothers' Wright Flyer engine—a liquid-cooled, four-stroke, spark-ignited, internal combustion engine. (Copyright National Air and Space Museum; used with permission.)

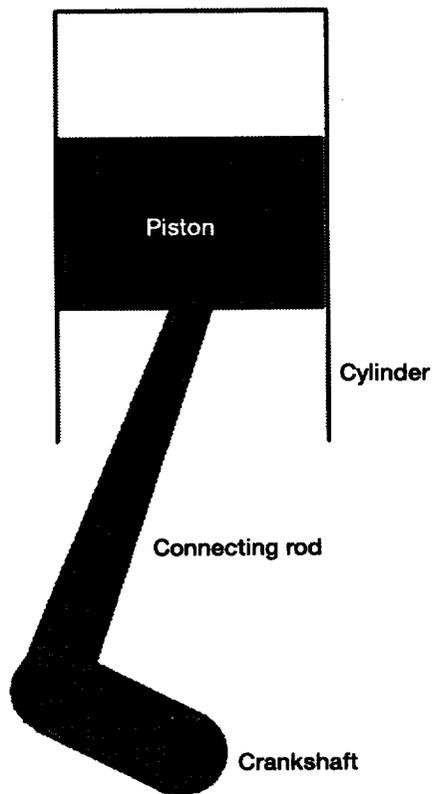


Figure 2.—Standard piston engine.

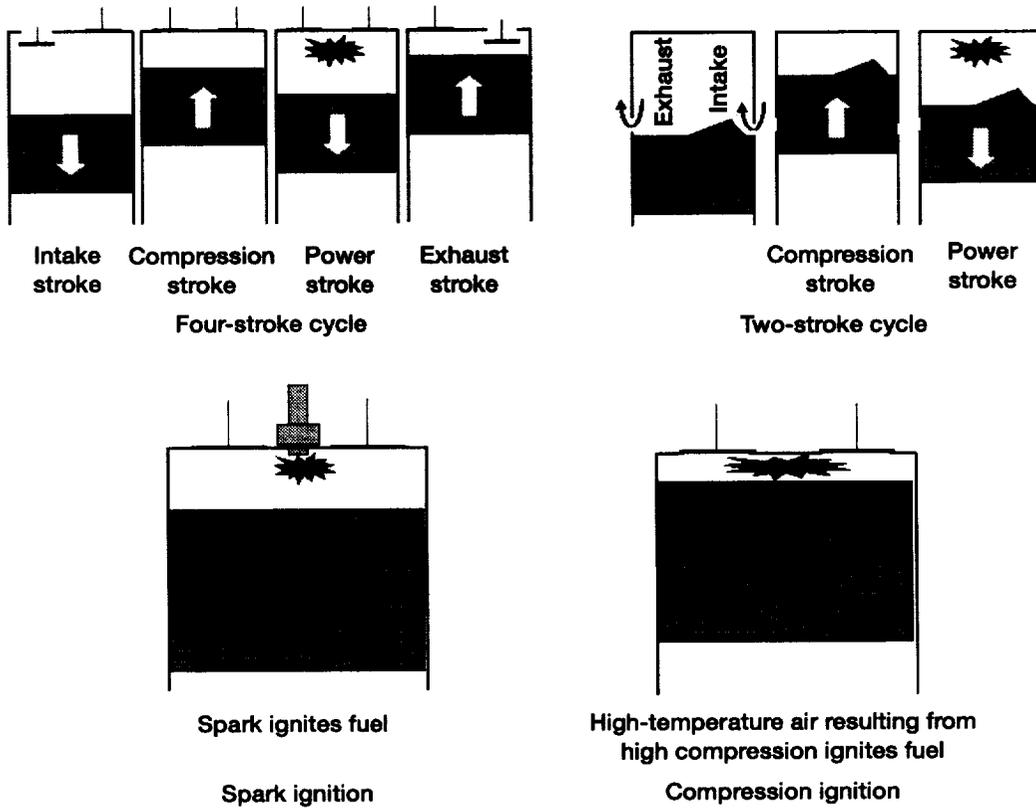


Figure 3.—Engine cycle types.

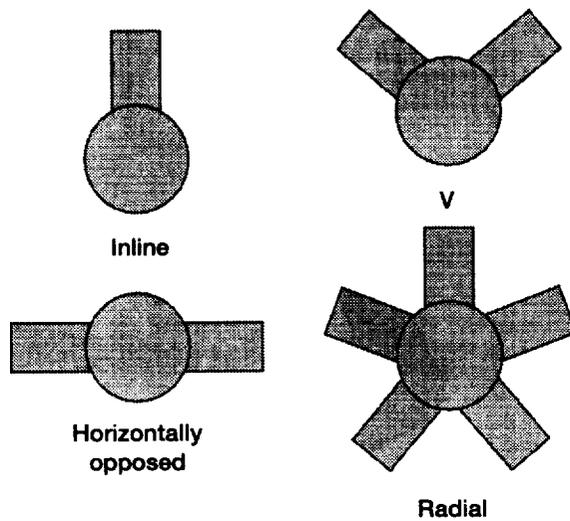
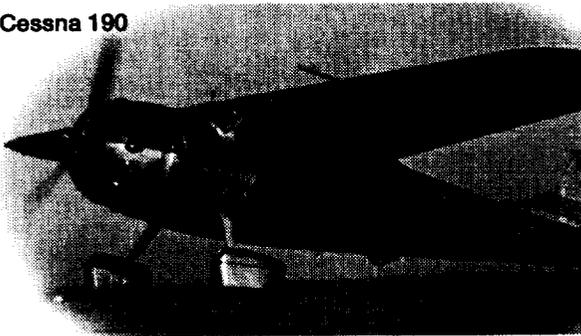


Figure 4.—Engine mechanical layouts.

Cessna 190



Cessna 182

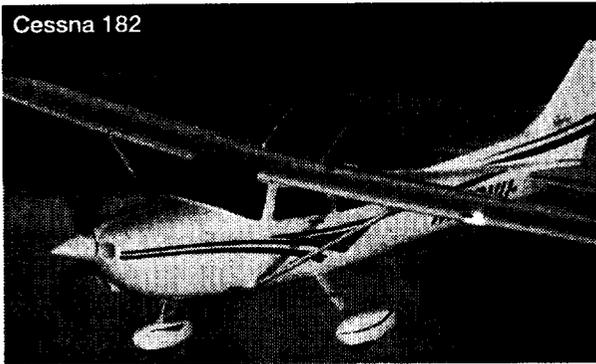


Figure 5.—Radial (Cessna 190) versus horizontally opposed (Cessna 182) engine installation. (Copyright Cessna; used with permission.)



Figure 6.—Continental A-40—first popular, horizontally opposed engine. It produced 37 hp at 2500 rpm. (Copyright Teledyne Continental Motors; used with permission.)

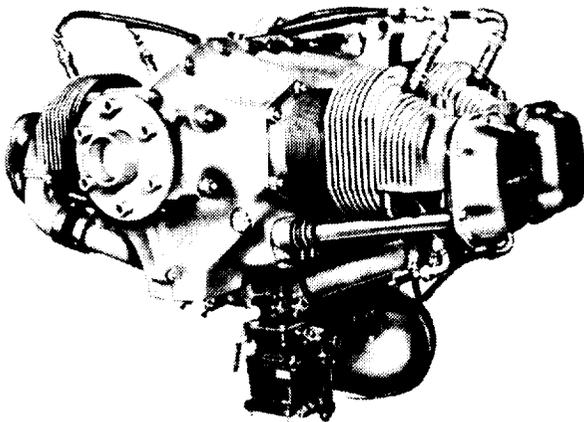


Figure 7.—Continental A-65—a horizontally opposed engine producing 65 hp at 2300 rpm. (Copyright Teledyne Continental Motors; used with permission.)

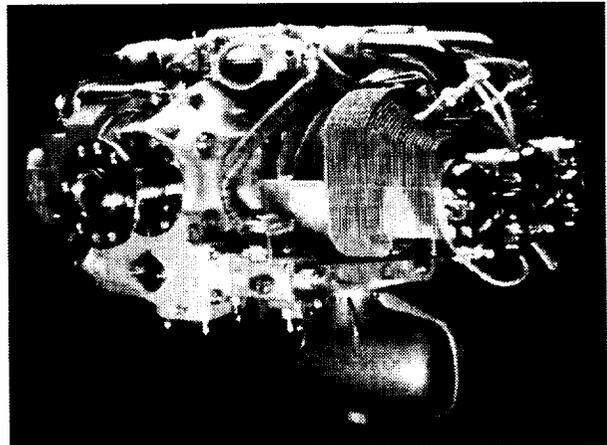


Figure 8.—Continental IO-240-B—a currently used, horizontally opposed engine. (Copyright Teledyne Continental Motors; used with permission.)

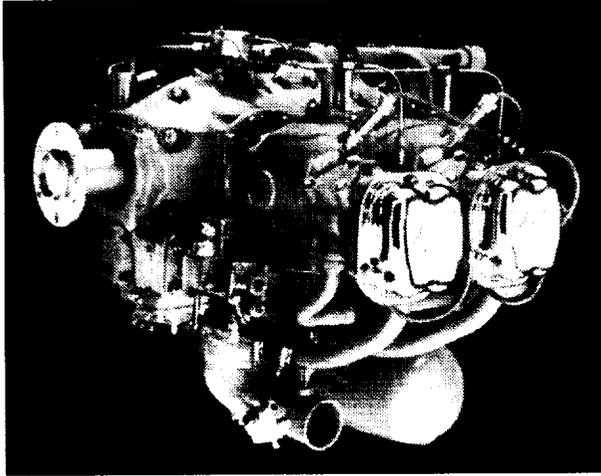


Figure 9.—Continental Voyager 200—a liquid-cooled engine. (Copyright Teledyne Continental Motors; used with permission.)

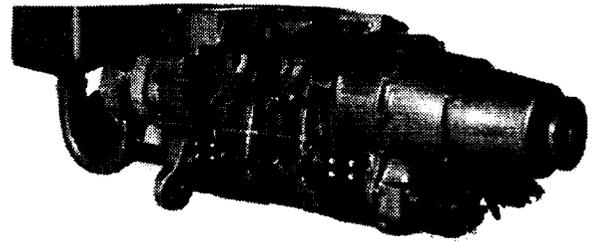


Figure 10.—Rotary Power International's Model 2013R Wankel engine.

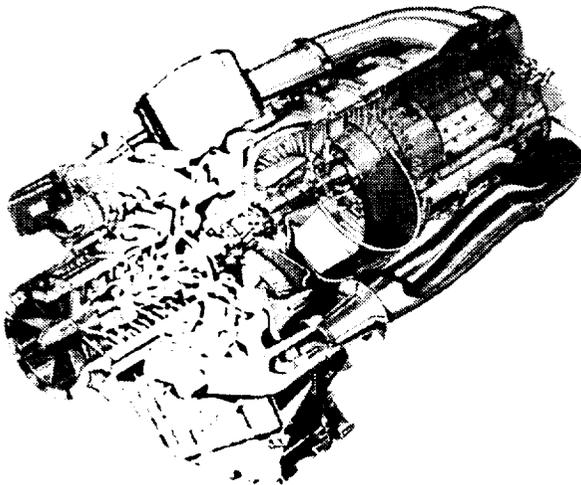


Figure 11.—Allison Model 250—a light aircraft turbine engine. (Copyright Allison Engine Co.; used with permission.)

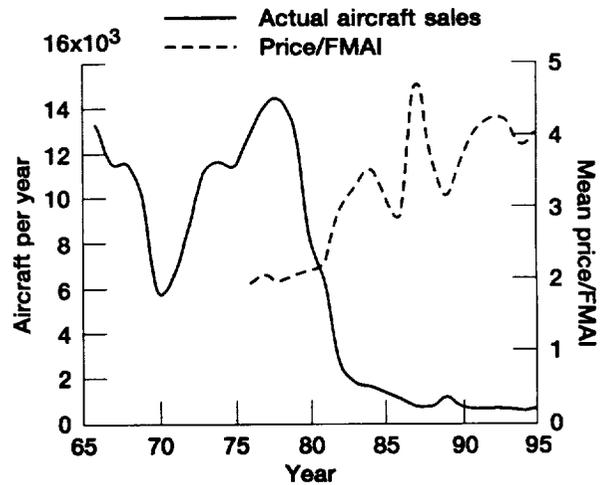


Figure 12.—Single-engine aircraft sales and price per family mean annual income (FMAI).

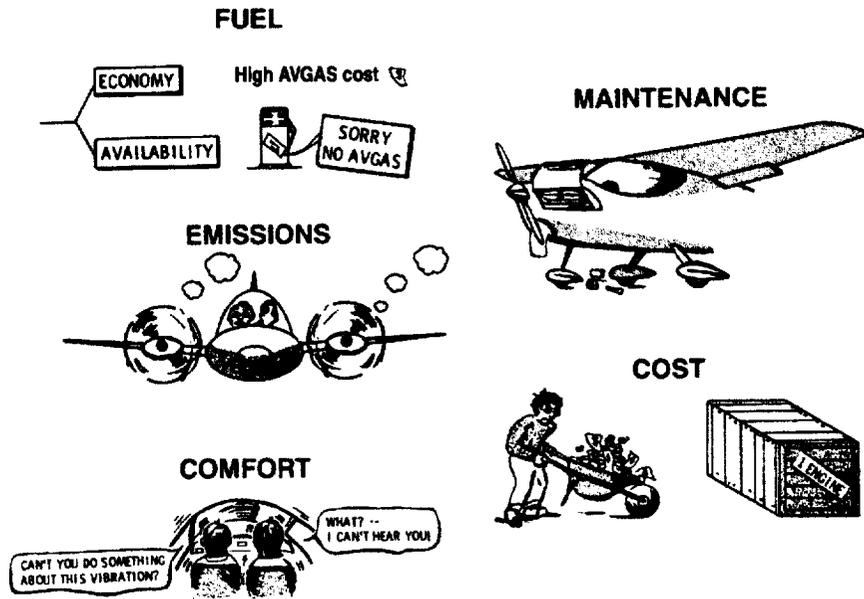


Figure 13.—Why light aircraft need new engines.

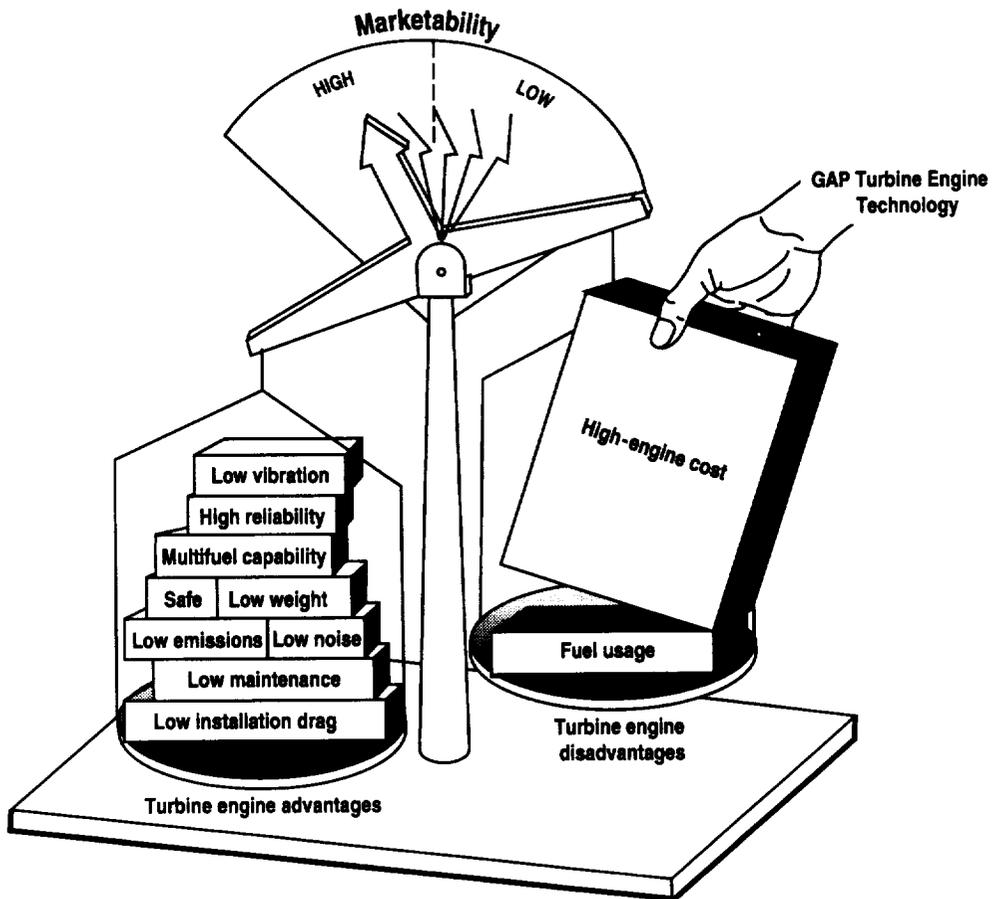


Figure 14.—Turbine engines are desirable but very expensive.

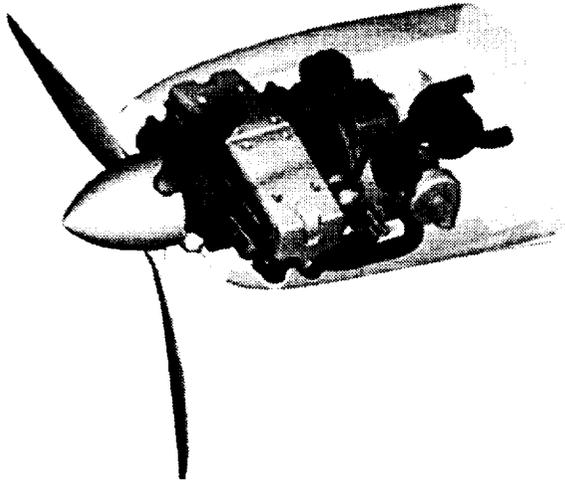


Figure 15.—GAP piston engine—an innovative, horizontally opposed, four-cylinder, liquid-cooled, two-stroke, compression-ignition engine.

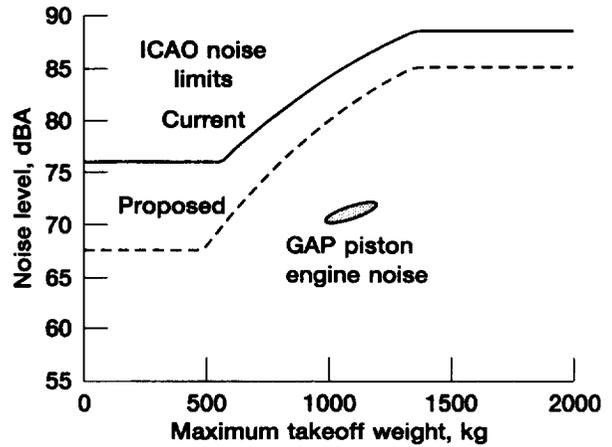


Figure 16.—GAP piston engine noise compared with International Civil Aviation Organization (ICAO) noise limits for propeller aircraft.

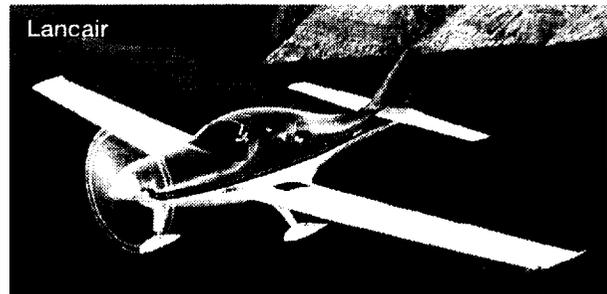
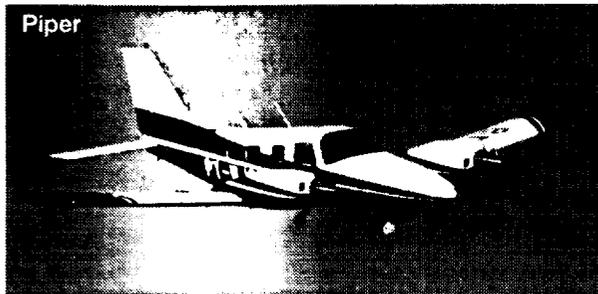


Figure 17.—GAP piston engine flight demonstration aircraft.

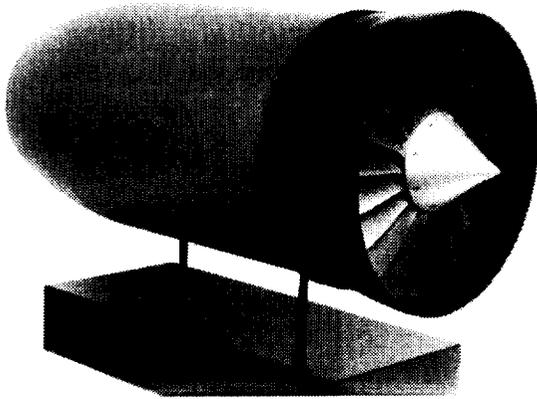


Figure 18.—GAP FJX-2 turbofan engine.

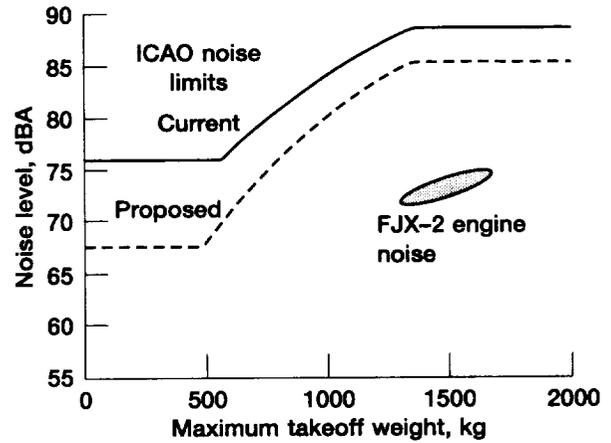
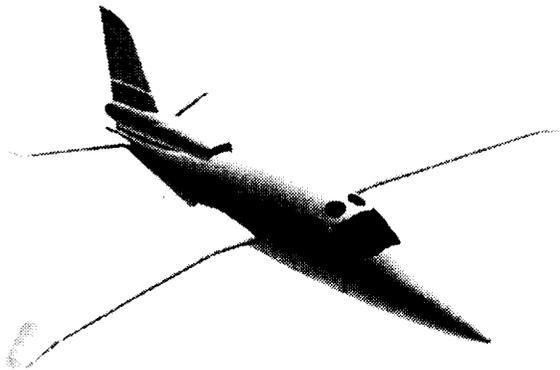


Figure 19.—FJX-2 noise compared with International Civil Aviation Organization (ICAO) noise limits for propeller aircraft.



<b>Weight, lb</b>	
Maximum takeoff .....	2900
Empty .....	1500
<b>High-speed cruise, kn</b> .....	
	280
<b>Range, mi</b>	
With maximum fuel .....	2300
With four onboard .....	1600
<b>Fuel economy, mpg</b> .....	
	13

Figure 20.—Aircraft performance estimate for typical single-engine turboprop.

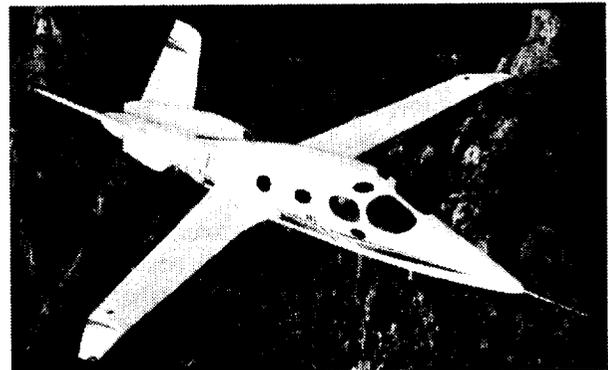


Figure 21.—V-Jet II turboprop (FJX-2) demonstration aircraft.

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